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REMOTE SENSING IN RESOURCE EVALUATION, PLANNING, PROTECTION AND MANAGEMENT

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SUMMARY

Because the forest is a fragile and renewable wildland resource of multiple values, the administrator of forest land is continually faced with a complex of interacting interests and must have at his disposal current information on the total resource before making decisions. Data from which this information is derived can be supplied by remote sensing systems.

The principal remote sensing devices, which include photographic cameras, television cameras, scanning radiometers (scanners), radards, and spectrometers, are described and their utility and the type of data gathered by them are discussed.

Once the spectral "signatures" for wildland resources and the appropriate computer programmes are developed, the data can be analyzed and converted to useful information and stored by geographic location. Such information would have ready application by planners, policy-makers, and managers in many disciplines.

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All too little is known about the world's forests as they are today. Most studies to date have only considered the timber production aspects of the forest and only looked at the other roles of the forest to the extent they affect the capacity to produce wood. Forests have not been surveyed over large parts of the world and where they have, much of the data is seriously outdated and all that can be reported on a national or regional scale is estimates of forest areas and major forest conditions. However, forests constitute a principal form of land use covering nearly a third of the world's land surface.

The value of this resource to the world's people, and the importance of sound policies and wise management governing it, becomes apparent when we consider its contributions to man's way of life. Timber, the raw material for lumber, plywood and paper, has historically been regarded as the primary output. In many parts of the world, this is closely followed by the importance of grass and herbage output for conversion into meat. In the last couple of decades, we have come to recognize and appreciate other resource values. These are less tangible but in their total contribution to mankind may outweigh the others. They include the opportunities for outdoor recreation, clean water and fresh air, food and shelter for wild birds and animals, and the simple pleasures of trees and parks, mountains and valleys, spring greenery and fall colors. When considered in terms of all these values, the forest becomes a wildland resource.

Most of the components of the wildland resource have two things in common. First, they are expendable and can be renewed or even enhanced through effective protection, wise use, and good management. Second, they are in a sense fragile, and their values can be ephemeral, with rehabilitation a long and costly process if they are exposed to neglect, destructive forces, overuse or mismanagement.

Thus, the administrator of forest land is continually faced with a complex of interacting, often conflicting or competing interests. He must have at his disposal current information about the condition of the total resource before making decisions. He is also well-advised to closely monitor the consequences of his decisions in terms of what happens to the component--trees, soil, waters, wildlife, and other vegetation.

The observation of management success or failure on our forest lands--and the need for a continuing early warning system to prevent losses from various causes calls for increasingly effective and timely management information systems. Fortunately, the technology of remote sensing offers promise as a highly versatile and economically feasible data gathering and manipulating tool. At this point two facts with regard to remote sensing must be brought out. First, remote sensing in this discussion is not limited to aerial or space photography but is considered a system, (including ground observations) for collecting, processing and analyzing aerial and space surveys of the earth's resources. Second, data are not information and quite often the cost of extracting meaningful or significant information from data is high and represents a very time consuming step. Adding to this problem is the fact that the kinds of information available from the more exotic remote-sensing data are not very well understood nor are their utility demonstrated at the present time.

Along these same lines, remote-sensing data are not answers in themselves and will not be a panacea for our entire informational requirements. They will not prevent or solve environmental problems. However, they can supply the basic data from which the information required by planners, policymakers, and managers can be derived as well as allow a clearer view of conditions as they exist today and observation of the rate and direction of change. Obtaining and evaluating data on a continuing and timely basis should allow the necessary leadtime to make planning and operational programs more effective. Thus, the limited resources of the planners and managers can be brought to bear upon the most urgent problems.

An early form of remote sensing was the use of photographic cameras operating in the visible part of the spectrum and recording scenes very nearly as man sees them. They are still the most important kind of remote sensor. Photographic cameras being relatively simple can be made to rigorous standards and can be employed to measure accurately the locations, shapes, and sizes of objects. Stereoscopic photography in which the same scene is recorded simultaneously from two slightly different angles, makes it possible to measure in three dimensions. Similarly, acquisition of repeated photographic coverage of a particular scene adds the dimension of temporal change which is often useful in interpretation.

Black and white panchromatic film is the most economical and most commonly used type. Color film increases by many times the value of photography for the identification of such things as rocks and soils, vegetation, surface water conditions, and materials in houses, roads, and other structures. Thus, the information may be less expensive to obtain when color films are interpreted.

Infrared films respond to wavelengths sensitive to radiation just beyond the visible--reflective infrared. One kind of infrared film produces a black and white image. A second type, color infrared, records in colors that are not true to nature but are designed to make it easier to distinguish conditions of vegetation. Exposure is made through a yellow filter which blocks the passage of blue light and admits green, red and infrared light. It was developed especially for camouflage detection, and red color is made representative of live vegetation to enhance the contrast between it and dead vegetation which appears in other colors. Leaves of healthy plants generally have high reflectance in the infrared; the amount of reflectance varies with leaf structure and geometry and with plant vitality. Thus, variations of red color on infrared film may indicate the presence of different species, and the diminution or absence of red color in certain members of a single planting is likely to indicate diseased or dead plants.

Distributions, growth rates, and vigor of vegetation vary with the physical character and mineral constituents of soils and the availability of water. Abnormalities in the distribution or condition of vegetation observed in infrared photographs may, therefore, give clues to increasing salinity of irrigated soils, proximity to ore bodies, and changing water tables.

The availability of data in more spectral regions has now made it possible to select bands in which the necessary degrees of contrast are best represented. Multi-camera arrangements with each camera viewing the same scene but with each camera only recording data for a specific portion of the spectrum have enabled processing and analysis of multispectral photography of the various wavelength bands.

Photography has been used in almost every phase of resource evaluation, planning, protection and management. Photography is used routinely for the preparation of topographic maps. It is used widely by agriculturalists, foresters, and rangeland managers to map soils, to plan roads and other developments, to examine range, crop, and timber stands for harvest, to estimate potential yields, to detect disease, and to assess storm damage. Other users include archeologists and anthropologists, geologists, geographers, highway engineers, hydrologists and engineers. Emergency relief agencies also use it to determine the extent of damage from storms and earthquakes and to plan rescue and rehabilitation measures.

Television cameras also operate in the visible and near infrared range and transmit both black and white and color data. They are important to remote sensing because they do not require film or any other material medium for the transfer of the data they gather. This makes it possible for the user of the data to obtain it, even from long distances, such as from satellites at the same time that it is being gathered. Using such a system the surface of the earth can be viewed over long periods and under environmental conditions in which photographic film without protection would deteriorate from the effects of heat or radiation without the need for recovery of the equipment.

The initial Earth Resource Technology Satellite (ERTS-1) utilizes television cameras as one of its primary data collection systems. The three cameras have been referred to as a Return Beam Vidicon (RBV) system and sense in the green, red and near infrared wave length.

In recent years airborne optical-mechanical scanning radiometers, or scanners, which operate in the ultraviolet, visible and infrared, energy regions have begun to play a role in meeting resource management information needs. Some of the newer scanners, called multispectral scanners, can image the earth in several spectral bands simultaneously through a single optical system. Unlike cameras, which record all parts of a scene simultaneously, scanners sense one spot at a time, covering the surface by sweeping their view from side to side as the aircraft moves forward. This is accomplished by means of rotating or oscillating mirror. The incoming radiation is focused on a detector, which translates its intensity into a corresponding electrical signal. This signal may be used to activate a cathode ray tube that reconstructs the scene line by line in the manner of a television set, and the resulting picture can then be photographed. Alternatively, the signal may be used to energize a glow tube that exposes film directly. Pictures produced by these means are called images to distinguish them from photographs. The data can also be recorded on magnetic tape and used to produce an image later. Scanners can measure simultaneously the energy being received in a number of narrow wavelength bands and record each amount separately.

The ERTS-1 system has an oscillating scanner which provides six scan lines in each of four spectral bands simultaneously. Data from multispectral scanners and the availability of high-speed automatic data processing equipment have made the automation of this data comparison task economically feasible. Multispectral scanners are just beginning to be exploited in the management evaluation, planning and protection of resources. Applications include enhancement of those discussed under the individual scanners.

For visible wavelengths, scanners have an advantage over cameras in that they observe radiation in narrower wavelength bands with more precision. When the data is recorded on magnetic tape the electrical signal can be amplified and combined for computer analysis. On the other hand, images produced by scanners are subject to distortions caused by the motions of the mirror and the aircraft. For example, straight lines may appear S-shaped unless corrected.

Infrared scanners can sense temperatures at and near the earth's surface.

Measurements of temperatures and mapping of their distributions are of wide-ranging value in resources and environmental studies. Thermal infrared scanner imagery can reveal surface temperatures that indicate diseased plants, animals obscured by darkness, and heated buildings. It is used operationally by the U.S. Forest Service to detect and map forest fires through the smoke pall common to forest fires. It has been used to map geothermal steam fields in California and Iceland. It can reveal surface temperature distributions in water, aiding in the discovery of sources of fresh water, sources of water pollution, or oil discharging into lakes, rivers, and oceans. Infrared scanners are useful in mapping the distribution of soil moisture near the surface, because variations of soil temperature are related to variations of moisture. In turn, information on moisture distribution provides clues to the identities of soils and rocks because their retention or loss of moisture is determined by their physical characters.

Microwave imaging radiometers sense temperature variations at longer wavelengths--millimeters and centimeters--than those of the thermal infrared scanners. Because the wavelengths at which they operate are longer, they can sense to greater depths than any of the systems previously discussed. This makes them especially appealing to geologists and hydrologists, who are very much concerned with conditions below the surface of the earth. Experiments are being conducted with microwave systems mounted in trucks and in helicopters to determine their utility for the detection of underground caverns and geologic faults and fractures, and for the measurement of soil moisture and the water equivalent volume of snow.

Radars operate at microwave frequencies and the higher radio frequencies. They emit pulsed signals at predetermined frequencies, polarizations, and rates, and measure the changes in these variables in the "echoes" returned from the ground. Because radars generate their own radiation, they can be used to obtain terrain information even in darkness. Their relatively long wavelengths enable them to operate in cloudy weather.

The returning signals are affected by the roughness and orientation of the surface from which they are reflected and the electrical properties of the material. At the shorter wavelengths, surface characteristics are predominant; at the longest wavelengths and in dry materials such as desert soils and very cold ice, sharp boundary conditions at some depth may also be sensed.

Radars may be imaging or nonimaging. Airborne imaging radars scan across the flight path in a vertical plane that may extend to both sides or only to one side of the aircraft. The type that has been most used in environmental studies looks to one side and is commonly called SLAR (Side Looking Airborne Radar). As in the scanning radiometer, the signals received from each scan are converted to electrical impulses recorded on magnetic tape or used to create a photographic film record. New lines of data are added with forward movement of the aircraft, producing a continuous strip image. Image paths on the ground may be as wide as 50 miles and data can be obtained as quickly as the aircraft can fly. The ability to obtain rapid coverage of large areas and to function in cloudy weather made it possible in 1970 to start a project to map natural resources and analyze environment factors in the Amazon Region of Brazil, (RADar in the AMazon-RADAM) where for years almost perpetual cloudiness had frustrated attempts to use photographic cameras.

Radar images show less surface detail than aerial photographs, but this is an advantage for some purposes in that the very abundance of detail in photographs can obscure certain subtle features of the terrain. Radar imagery is especially useful to geologists for revealing structural conditions, especially faults and fractures that are only poorly expressed at the surface and are difficult to detect in photographs. Knowledge of fault and fracture systems is important to the finding of ores and ground water. The big advantage of radar for vegetative mapping is that it can operate independently of cloud cover and gives the same image regardless of illumination or sun angle.

The last sensor group we will discuss includes spectrometers. Airborne spectrometers differ from cameras and scanners in that they do not scan but observe radiation from individual spots on target areas. To determine exactly which areas have been sensed, the times of sensing are correlated with information about the position of the aircraft at those times. Comparison with photographs and scanner images obtained simultaneously helps to determine the positions of any anomalous conditions observed.

A specialized spectrometer, the Fraunhofer line discriminator, can detect and measure concentrations of substances that fluoresce. Fluorescence occurs when materials receiving radiant energy are stimulated to emit energy of another wavelength. It occurs in many materials but is not normally apparent out of doors where its presence is obscured by sunlight.

Fraunhofer lines are dark lines in the spectrum of the sun--narrow wavelength bands in which the sun's radiation is weak. At these wavelengths fluorescent radiation emitted by substances on the earth can be distinguished from the background of solar radiation. The Fraunhofer line discriminator looks alternately at the sun and the earth, and for each it compares the intensity of radiation at the Fraunhofer line with that at some other point of the spectrum. If the relative amount of radiation at the Fraunhofer line is greater in the light received from the earth than it is in the natural sunlight, the excess is attributed to fluorescence. The instrument has been used to measure the concentration of a fluorescent dye in water. It is being modified to detect chlorophyll, certain minerals, and fluorescent compounds. If successful, this will provide a rapid reconnaissance system for such purposes as monitoring the condition of vegetation and surface waters as well as recognizing surface minerals.

We have finished our discussions of the sensors used for data collection in remote sensing. The next step is the processing and analysis that converts the sensed data to meaningful information. Once spectral "signatures" are developed for wildland resources, printouts can be made of these "signatures" in their proper geographical location, for example, computer programs have been developed to identify crop species, geological differences and identify them with a geographic position. Also digitizing of broad delineations enables a geographic display of the wildland resources and can show the overall interaction of the environment. Computer programs have been developed that complete union and intersection manipulation of data for establishing geographic management units within the wildland resources. In the future, once these units have been established, they can be monitored from satellite with a direct reading on the effects management has had on the wildland resources. Once the basic data has been incorporated into a coordinated map system, then we must decide what kinds of information are needed by land managers for resource evaluation, planning, protection and management.

This fixed information includes placement of land ownership, boundaries, ridge structure, slope, aspect, major roads and streams, and urban developments. This information by itself is suitable for cartographic and engineering purposes for major land use categories or early stage resource development plans. When added with other detail information, it becomes the basis of an information system. This type of information should enter into the information system as base data and not be subject to constant resubmission, but only on a change basis. Small scale high altitude (50,000-60,000 ft. altitude) aerial and satellite photography and imagery, provide a synoptic view and are prime sources of data for this kind of information.

Another type of information needed by resource managers is detailed in-place information. However, we cannot afford a complete itemization of in-place data and sampling designs must be used. This kind of information describes resources and resource situations and is needed as a basis for decisions affecting many kinds of programs and activities. Detailed information varies from the fixed category in the amount of data needed to describe the attribute and it also requires a standard procedure for updating. For example, soil delineation may be shown with a simple descriptor, however, there are many factors like depth, texture, fertility that must be routinely sampled to keep a correct classification. The detailed information category includes vegetation, hydrology, soils and identifiable pollutants. The cycle of sampling may be on an hourly basis as in the case of tracking the progress of a forest fire or it may take 5 years of records before it can be finally determined whether a grazing allotment is really recovering from the impacts of former overuse.

The density or degree of detail in which these data are stored in an information system is critical to the system's success. It has become apparent that a regional or national data center cannot afford to store all the data the resource manager or land manager thinks he might need. It is here, that remote sensing will play its biggest role as a management tool in stratifying and grouping data into meaningful information as it enters the system.

After the data has been entered into the system and meaningful information is displayed, it is time to analyze and monitor what is happening to the resources; that is, to measure and interpret the change in resource condition or productivity. Ecosystems are rarely, if ever, static even without man's disturbing influence. Therefore, it is important to observe, record and understand the direction and rate of change where important resource values are involved. Answers mut be produced for a variety of questions. For example, what has been the shift in major land use since 1960? What is the saw timber volume of slash pine in Florida compared to what it was 5 years ago? How fast and in what directions is the gypsy moth spreading in the northeastern United States? How much area was cut over last year? Where did timber removal take place?

Let us next consider what we do with all this information stored by geographic location. A monitor (may be - photography, radar or scanning imagery) could detect and geographically display an unvegetated area within our forest. An inquiry of the information system shows the area was burned by wild fire 3 years ago. Stored information about the area could show it to be a good growing site, a direct effect on a watershed, and aesthetic value to a community. The area has not naturally regenerated since the fire but the soil and climatic conditions will give a 85 percent change of survival for Ponderosa Pine 2-0 stock. The decision is made to plant next fall. You will notice all this information is included in the kinds discussed above and at an attribute density that could feasibly be stored in a regional or national system.

Why so much concern about the use of remote-sensing technology? As technology and costs permit, the area of resource management information will ultimately represent extremely widespread and diverse remote-sensing applications. At present available data are often unreliable or badly out of date. The so-called solid reference points, such as maps, which we rely on so confidently, often contain serious distortions, omissions, or inaccuracies. Revision or correction by conventional methods is slow and costly. Thus, present solutions to the multitude of specific resource problems or decision situations must rely upon scanty data of questionable reliability. This is supplemented only by the skill, knowledge, and experience of the resource manager and his staff. The high cost, length of time, and physical difficulties involved in obtaining the needed information as accurately and as often as required by ground methods alone is an impossible task. Although remote-sensing systems will not in any sense solve our entire informational problems, remote-sensing technology along with minimal ground truth offers the only economically feasible way to obtain and evaluate data on the continuing basis needed that will make available the leadtime necessary to make program effective. Trouble spots such as insect infestation can be identified, and resources of the planners and managers brought to bear upon the most urgent problems.

In recent years we have seen great advances in remote-sensing technology. Weather and poor visibility are now no longer necessarily a barrier to data acquisition. We can now sense radiation from the ultraviolet to the microwave regions. We have also seen development of enchancement techniques that range from simple filtering to use of multispectral scanners. What then will be the future role of remote sensing in proper use and management of resources?

In the future we will undoubtedly see remote-sensing systems that have a much greater sensitivity and precision than anything we have seen to date. Information systems will be developed that will take full advantage of this data gathering capability. As indicated earlier, management units will be defined and geographically located in our file system to give timely responses to our information needs. These management units will be large enough to allow for monitoring the wildland resource from satellite. Resource managers will be able to spend more time deciding what they want to know, when they want to know it, and how well they need to know it. Much less time will be spent in manually acquiring ground data and reducing remote-sensing data to needed information.

Remote-sensing instruments, techniques, and systems capable of even greater sensitivity and precision in target discrimination than are now available will be required to increase the use in resource development. The equipment that can automatically separate rectangular fields of wheat and soybeans will need further development to separate Engelmann spruce from the half dozen other species in the mixed conifer forest of the central Rocky Mountains. The sensing of such diverse parameters as insect and disease injury or the response of a young forest stand to fertilizer applications will require more research and development.

We have already seen some of the advances in sensor technology that: (1) Minimize the barrier of poor weather for data acquisition, (2) Shows the advantage of data acquired simultaneously in many spectral regions, and (3) How remotely sensed data lends itself to reduction by computer.

If the true potential of present and prospective sensor technology is to be achieved, many application studies are needed to show how to best extract needed information from the data available. Also important will be research to develop informational and spectral response models that accurately portray resources and resource situations under various management schemes. Information demands can then become specific. Only then can the full capabilities of remote-sensing systems be brought to bear in an effective and efficient manner.